Frequency Control of Micro Grid with Wind Perturbations using Levy Walks with Spider Monkey Optimization Algorithm

S. Kayalvizhi*‡, D.M. Vinod Kumar**,

*Department of Electrical Engineering, National Institute of Technology Warangal, India.

**Department of Electrical Engineering, National Institute of Technology Warangal, India.

(*kayaleee89@gmail.com **vinodkumar.dm@gmail.com)

‡ Corresponding Author; S. Kayalvizhi; Department of Electrical Engineering, NIT Warangal, Tel: +918142497171, kayaleee89@gmail.com

Received: 13.09.2016 Accepted:09.12.2016

Abstract- Frequency and voltage controls are the two main challenges in the micro grid operation both in the grid connected and autonomous mode due to the presence of uncertain renewable sources. Since economic micro grid operation relies on fluctuating renewable sources such as wind and solar, the task of maintaining frequency within the limits for smooth operation of micro grid demands advanced controller action. Keeping this in mind, a panoptic exploration to search space has been accomplished using proposed eagle strategy for optimizing the gains of PI controller employed in controllable generating units in the islanded micro grid. The proposed eagle strategy which made the search process two fold i.e., coarse search by levy flights and an intensive local search by spider monkey algorithm. The proposed strategy has been tested on typical micro grid test system and also on real world Bella Coola micro grid in British Columbia, Canada. Frequency model of systems were developed in SIMULINK/MATLAB and the simulation results for different scenarios confirms that the proposed strategy performs better and the results are compared with few prominent algorithms to ascertain its superiority in finding better gains of PI controllers.

Keywords- Frequency control, eagle strategy, micro grid, wind components

1. Introduction

Steady increase in demand in the expanding power system leads to the situation of increased transmission and distribution losses to meet the loads at downstream of power system. This situation also increases pollution and depletion of fuel due to excessive use of conventional thermal power plants. This phase of power system is slowly evolved with the introduction of renewable energy sources such as wind, solar etc., in the power system. This sources being small in their capacity are preferred to be connected at the distribution network where loads are at their vicinity. Thus, these small Distributed Generations (DGs) connected near to the loads transforms the passive distributed network into active network thereby reducing the transmission and distribution line losses [1]. DGs not only limited to renewable sources but also includes controllable sources such as diesel units, fuel cells, gas turbine, storage systems etc. The small community of loads along with multiple generations and storage assets interchangeably called as Micro grid in recent times. A typical micro grid operates in two different modes i.e. autonomous/islanded mode and grid connected mode [2]. Increased interconnection of renewable DGs lead to many technical challenges to maintain reliable operation of micro grid. Economic scheduling i.e., dispatching DG units under supply and demand uncertainty, appropriate Demand Side Management to meet consumer needs, voltage and frequency control in case of power electronics interfaced DGs are the few challenges to mention [3]. The presence of fluctuating power sources such as PV, wind turbines may leads to stability and power quality issues. The frequency and voltage control are the major concerns in the micro grid operation and control.

In grid connected mode, the frequency deviation due to variations in load and renewable sources are regulated by the infinite grid connected to the micro grid whereas when there is no grid support to the micro grid, it depends solely on the proper control and scheduled operation of the DG sources connected to it. Here the frequency regulation is entirely depends on the dispatchable sources such as diesel and storage assets. Among various control strategy discussed in [3], conventional frequency droop controller is predominantly used in control methods. Two droop control methods have been proposed in [4] for acceptable load sharing with frequency droop controller. First method considers no communication with DGs and the second one considers minimal bandwidth communication with DGs to regulate voltage and frequency. In case of islanded mode, Energy storage systems plays an important role as that of synchronous generator based diesel units in absorbing the power mismatches between generation and demand to support frequency in micro grid. In [5]-[7] enforced the benefits of various energy storage systems in frequency support of micro grid operation especially in the autonomous mode. Amir et al. [8] proposed a mathematical framework combining frequency control consideration in the generation scheduling in the autonomous mode of micro grid. Micro grid reserve power requirement is emphasized more in the operational constraints to regulate the frequency with the help of isochronous load sharing mode. In [9] and [10] analyzed the small signal stability of an autonomous micro grid using time domain simulations. They also studied the time domain performance of the system under various normal operating and disturbance conditions. M J Sanjari in [10] used small signal stability assessment to define parameters in fuzzy potential function for controllable micro sources. Apart from this conventional control techniques and methods employing droop characteristics, intelligent algorithms based control techniques are also growing equally in frequency regulation studies in power systems [11] - [14]. Application of inteligent algorithms is not only confined to PI controller tuning in frequency regulation studies but also applied to tune gains of the PI controllers employed in pitch control of wind energy conversion systems [15].

Senju T et al. in [16] proposed a hybrid power system consisting of wind/diesel/fuel cell/ aqua electrolyser and analyzed its system response under different operating conditions. Here the PI controller gains are chosen by trial and error method. H. Bevrani et al. in [17] proposed an online intelligent technique by combining fuzzy logic and PSO algorithm for frequency regulation in an isolated micro grid. The frequency control has been implemented by tuning PI controller gains for different case studies. Similarly in [18] Bacterial Foraging optimization Algorithm (BFOA) has been used to tune PID controller gain employed in frequency control in the presence of central controller of an isolated micro grid.

In this paper, load frequency control of typical micro grid is analyzed for its autonomous operation. The frequency deviation due to the changes in load and renewable sources is regulated by the controllable sources to maintain frequency deviation within the specified limits. This is achieved with the help of PI controllers employed along with the controllable DG sources. The gains of the PI controller are tuned in such a way to track the power mismatch between generation and load. Several intelligent/heuristic algorithms were adopted for tuning the PI controller gains but many of them limited their validation only with the conventional Ziegler–Nichols methods that too only with micro grid test systems. This paper proposed a novel Eagle strategy by combining levy flights with Spider Monkey Algorithm (SMA) for tuning gains of the PI controller. Use of levy flights [20] made the search process extensive in exploring the values of gains K_p and K_i within given limits to track the frequency deviation in the system.

The rest of the paper organized as follows: Section 2 explains the proposed Eagle Strategy in detail. The simulation model and the problem formulation are presented in section 3. Simulation results and discussions are compared and validated in section 4. Finally section 5 concludes the paper.

2. Proposed Eagle Strategy using Levy Flights with Spider Monkey Optimisation Algorithm

Eagle strategy worth called as methodology rather than algorithm is inspired from the foraging behavior of eagle where eagle search for prey in free random manner. Once the prey is found it will intensify its hunting process by chasing the prey. Eagle strategy was first developed by yang et al. [19]. The two main components of eagle hunting strategy include a coarse global search with enough randomness so as to explore a diverse search space and intensive local search. In this paper, this strategy first explores the search space globally using levy flight random walk for promising solutions and then an intensive local search is carried out with efficient spider monkey algorithm.

2.1. Levy flights

Random walk whose step length follows a non-Gaussian distribution such as levy distribution is called levy flights. It is often given in terms of simple power law $L(s) \sim |s|^{-1-\beta}$ where $0 < \beta \le 2$ is levy index. Mathematically, a simple version of levy distribution is given by [17].

$$L(s,\gamma,\mu) = \begin{cases} \sqrt{\frac{\gamma}{2\pi}} \exp\left[-\frac{\gamma}{2(s-\mu)}\right] \frac{1}{(s-\mu)^{3/2}} & if \quad 0 < \mu < s < \infty \\ 0 & if \quad s \le 0 \end{cases} \tag{1}$$

Where μ is shift parameter, $\gamma > 0$ is scale parameter. This is the special case of generalized levy distribution.
In general, levy distribution should be defined in terms of Fourier transform:

$$F(k) = \exp[-\alpha |k|^{\beta}] \qquad 0 < \beta \le 2 \tag{2}$$

Where, α is the scale parameter in range (0, 1). Inverse of the above Fourier transform is not possible except for few special cases when $\beta = 2$ corresponds to Gaussian distribution and $\beta = 1$ corresponds to Cauchy distribution.

In general, the inverse integral is given by

$$L(s) = \frac{1}{\pi}\int_0^\infty \cos(ks)\exp[-\alpha|k|^\beta]dk \quad (3)$$

It can be estimated only when $s \to \infty$

$$L(s) = \frac{\alpha\beta\Gamma(\beta)\sin(\pi\beta)/2}{\pi|s|^{1+\beta}} \quad (4)$$

The gamma function $\Gamma(z)$ is given

by $\Gamma(z) = \int_0^\infty t^{z-1}e^{-t}dt$ (5)

Where z is an integer. Levy flights are more efficient than Brownian random walk in exploring the unknown, large scale search space. This is due to its variance $\sigma^2(t) \sim t^{3-\beta}$ which increases much faster than the linear relationship $\sigma^2(t) \sim t$ of Brownian walk.

Implementation of levy walk:

There are two steps in generation of random walk with levy flights: choice of random direction which is drawn from normal distribution and generation of random steps which obeys levy distribution. The latter is achieved by efficient Mantegna algorithm and step length is given by:

$$step = \frac{u}{|v|^{1/\beta}} \quad (6)$$

Where u and v are drawn from normal distribution.

$$u \sim N(0,\sigma_u^2) \quad ; \quad v \sim N(0,\sigma_v^2) \quad (7)$$

Where,

$$\sigma_u = \left\{\frac{\Gamma(1+\beta)\sin\left(\frac{\pi\beta}{2}\right)}{\Gamma[(1+\beta)/2]\beta 2^{(\beta-1)/2}}\right\}^{1/\beta} \quad \sigma_v = 1 \quad (8)$$

2.2. Spider Monkey Optimization Algorithm

Spider Monkey Optimization algorithm proposed by JC Bansal et al. [21] is recently budding in the family of nature inspired meta heuristic algorithms. This algorithm is inspired from the foraging behavior of spider monkeys which follows certain fission-fusion social structure (FFSS) for their effective foraging action.

Features of Fission Fusion Social Structure:

- Initially spider monkeys survive in single group with 30-60 monkeys and lead by female leader (global leader) who is responsible for all sorts of decision making.
- In the foraging process, the group keeps on divided into small sub-groups till group members reaches minimum of 3-5 members in different directions each lead by individual female leaders (local leaders).
- At the end of foraging process all groups are combined together as single group to share the food.

This type of foraging movement will increase the effective search of food without foraging competition. The SMO algorithm is inspired from this social structure behavior and it involves following seven steps:

Step 1: **Initialization of population**

Populations of P spider monkeys are initialized with D dimensional vectors.

$$SpM(i,j) = SpM(i,j) + rand()*(SpM_{macj} - SpM_{\min j}) \quad (9)$$

Where, $i = 1,2,3........P$, $j = 1,2,3........D \cdot SpM_{macj}$ and $SpM_{\min j}$ are the maximum and minimum limits on the corresponding j^{th} decision variable.

Step 2: Local Leader Phase (LLP)

The position of each members of each group is updated based on the local leader experience and other group member's knowledge

$$SpMnew(i,j) = SpM(i,j) + rand()*(LL_{kj} - SpM_{ij}) + rand[-1,1]*(SpM_{rj} - SpM_{ij}) \quad (10)$$

Where, $SpM(i,j)$ is the j^{th} decision variable of i^{th} SpM (spider monkey). LL_{kj} is the j^{th} decision variable of the local leader in k^{th} group. SpM_{rj} is the j^{th} decision variable of randomly chosen r^{th} spider monkey from the k^{th} group where $r \neq i$.

Step 3: Global Leader Phase (GLP)

Based on the experience of the global leader and other members of local group, the position of SpM is modified.

$$SpMnew(i,j) = SpM(i,j) + rand()*(GL_j - SpM_{ij}) + rand[-1,1]*(SpM_{rj} - SpM_{ij}) \quad (11)$$

Where, GL_j is the j^{th} decision variable of the global leader and the j^{th} variable is randomly chosen from

(1,2,3……D). The position update process is done with the help of probabilities p_i .

$$p_i = 0.9 * \frac{fitness_i}{fitness_{\max}} + 0.1 \tag{12}$$

Step 4: Global Leader Learning Phase (GLLP)

Greedy selection is applied on the new population and existing population and population of size P is selected. The position with best fitness within updated population is considered as new global leader position. Meanwhile if the position of global leader is not changed for certain number of iteration (Global Leader Limit) then, the global limit count is incremented by one.

Step 5: Local Leader Learning Phase

In this phase, the local leaders in each group are updated in the similar fashion as that of the global leader by applying greedy selection by comparing the group members of existing and new population. The one with best fitness is updated as local leader of that particular group and if it is not updating its position for local leader limit, then local leader count is incremented by one.

Step 6: Local leader decision Phase

If suppose the local leader count reaches the local leader limit, then all the members of the group are either randomly initialized or updated with the help of global leader and local leaders.

$$SpMnew(i,j) = SpM(i,j) + rand()*(GL_j - SpM_{ij}) + rand()*(SpM_{ij} - LL_{kj}) \tag{13}$$

Step 7: Global leader decision Phase

In this phase, the global limit count is checked for its threshold global leader limit, if hits the threshold, then global leader will divide the group into two, then three and so on till it reaches the minimum members requirement in the group. Once maximum number of groups formed and the position of global leader is not updating, sub groups are combined to form a single group by the global leader.

Pseudo code for the proposed Eagle Strategy: Levy walks with Spider Monkey Optimization Algorithm

1. *Initialize the population X of size (P*NV); where P- population size ; NV - Number of variables.*
2. *Evaluate objective f(X)*
3. *While (iter< itermax)*

3.1. Coarse search by levy flights

*$X^{new}=X^{old}+\alpha$*Stepsize ;*
*Stepsize=0.01*step*(step -Xold(best));*
*Evaluate objective function $f(X^{new})$ / *using equation 4*/*
X^{int}=[X; Xnew]; / Combine existing and new population of size 2P* NV */*
*Update population X of size (P*NV) with better fitness from X^{int}.*

3.2. Intensive local search by SMO algorithm

- *X as initial spider monkey population i.e. SpM=X;*

→ *Local leader phase*
For all i=1:P
For all j=1:NV

$$SpMnew(i,j) = SpM(i,j) + rand()*(LL_{kj} - SpM_{ij}) + rand[-1,1]*(SpM_{rj} - SpM_{ij})$$

End For j
End For i

→ Global leader phase
For all i=1:P
For all j=1:NV

$$SpMnew(i,j) = SpM(i,j) + rand()*(GL_j - SpM_{ij}) + rand[-1,1]*(SpM_{rj} - SpM_{ij})$$

End For j
End For i

→ Global leader learning phase
Greedy selection on SpM and $SpMnew$ and population of size P is selected.
İf (GL_j position changed)
Update global leader
Else(GL_j position not changed for GLL)
GLC=GLC+1;
End if

→ Local leader learning phase
Greedy selection on SpM and $SpMnew$ and each group is updated.
İf (LL_j position changed)
Update local leaders of each group
Else(LL_{kj} position not changed for LLL)
LLC=LLC+1;
End if

→ Local leader decision phase
For all i=1:P
For all j=1:NV

$$SpMnew(i,j) = SpM(i,j) + rand()*(GL_j - SpM_{ij}) + rand()*(SpM_{ij} - LL_{kj})$$

End for i
End for j

→ Global leader decision phase
İf (GLC= GLL)
GL will divide the group into two, then three and so on till it reaches the minimum members requirement in the group
End if
İf (group=MG)&& (no GL position update)
All groups are combined to form a single group
End if
İter =Iter+1;

4. *Processing of results and validation*

3. Simulation Model and Problem Formulation

This section gives the details of the simulated case studies. In this paper two systems were simulated for the validation of the proposed algorithm. First system is the ac micro grid structure [17] and the second system is the Bella Coola Micro grid in British Columbia [8], a real micro grid in operation at Canada and the details of both systems are given as follows.

3.1. Case Study 1: A typical isolated micro grid

An isolated micro grid model [17] is considered as case study 1 and the load frequency model of the same is shown in Fig.1. More details of this system modeling and parameters selection can be referred from [16], [17] and [9].

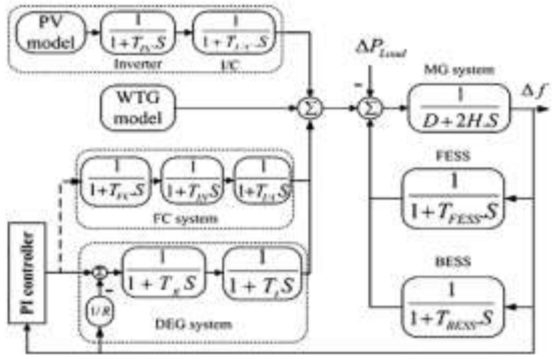

Fig.1. Case study 1: Frequency control model of an ac micro grid

3.2. Case Study 2: Conventional Bella Coola Micro grid

Bella Coola micro grid is a remote off-grid community in British Columbia, Canada. The major source of power generation is by diesel and hydro units. There are seven diesel units of size ranging from 300-1000 kVA with total capacity of 6.2MW and two hydro units with ratings of 720 and 1400 kVA. Apart from this one fuel cell and one aqua electrolyzer of ratings 100kVA and 320kVA respectively. There are two load points at Bella Coola and Hagensborg with maximum demand of 2.1MW and 2.6MW respectively [8]. The conventional Bella Coola micro grid is shown in Fig 2.a and the frequency response model of the same is shown in Fig.2.b. The parameter values of blocks of the losf frequency model (Fig. 2.b) are provided in Table 1.

Table 1. Parameter values of the Bella Coola Micro grid

Parameter	Value	Parameter	Value
D(pu/Hz)	0.015	T_t(s)	0.4
2H(pu s)	0.1667	T_1(s) and T_2(s)	48.7 and 0.513
T_{FC} (s)	0.26	T_w(s) and T_R(s)	1 and 5
T_{IN} (s)	0.04	K_1	1
$T_{I/C}$ (s)	0.004	T_{AE}(s)	0.2
T_g(s)	0.08	R(Hz/MW)	2.4

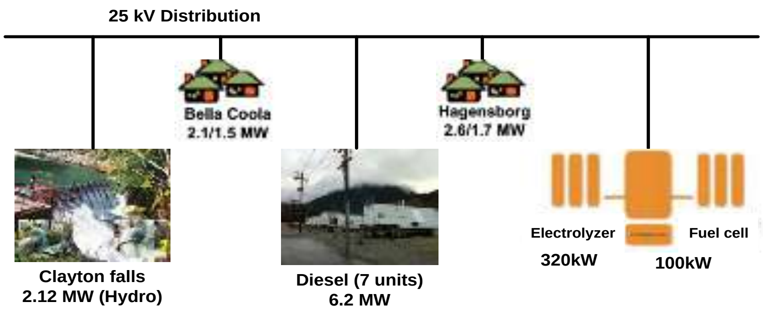

Fig. 2.a. Case study 2: Conventional Bella Coola microgrid

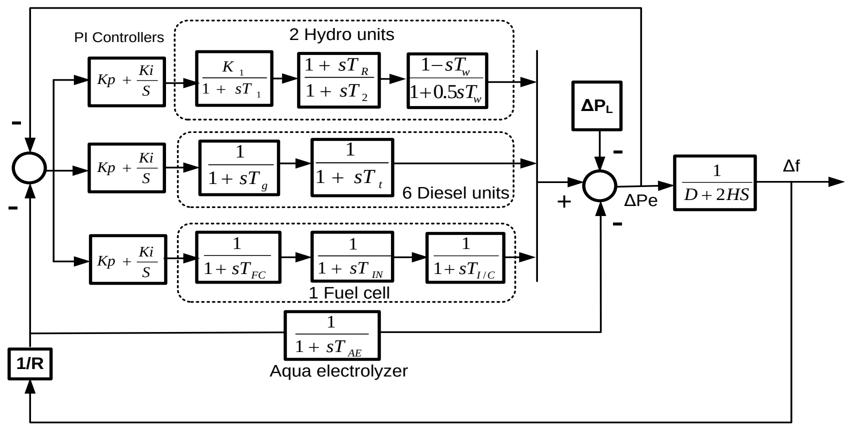

Fig. 2.b. Case Study 2:Frequency control model of bella coola micro grid

3.3. Problem formulation

In conventional power systems, the secondary control is required to regulate the frequency by tracking the power mismatch between generation and load. In traditional practice, it is done by conventional PI controllers. For the effective frequency regulation in case of change in operating conditions, the PI controller gains have to be tuned properly to achieve the desired performance. In this paper, the proposed Levy based Spider Monkey Algorithm (Levy-SMA) has been used to tune the PI gains for the better performance in tracking the power deviations to zero and effectiveness of the proposed algorithm has been evaluated and compared with performance metrics Integral Time Squared Error (ITSE) and Integral Squared Error (ISE) which are given by the following:

$$ITSE = \int_{0}^{Tsim} t * |\Delta f|^2 \, dt \tag{14}$$

$$ISE = \int_{0}^{Tsim} |\Delta f|^2 \, dt \tag{15}$$

Subject to:

$$\left.\begin{aligned} K_{p,\min} \le Kp \le K_{p,\max} \\ K_{i,\min} \le K_i \le K_{i,\max} \end{aligned}\right\} \text{PI controllers} \tag{16}$$

Where $K_{pi,\min}$ and $K_{pi,\max}$ are the minimum and maximum values of PI controller gains. $|\Delta f|$ and $Tsim$ are the absolute value of the frequency deviation and total simulation time respectively. The optimization problem is formulated as minimization problem with ITSE as objective function by optimizing K_p and K_i values as the decision variables.

4. Results and Discussion

This section presents the simulated results of various scenarios of the two case studies which are considered in this paper. The sampling period for case study 1 and case study 2 is taken as 0.01secs.

4.1. Case study 1

In this paper, the frequency regulation is achieved by tuning PI controller gains which are optimized by the proposed algorithm. PI controllers are placed only for the controllable units i.e., diesel units and fuel cell. There are two PI controllers for case study 1 and corresponding gains are K_{p1}, K_{i1} and K_{p2}, K_{i2} respectively for diesel unit and fuel cell. Fig.3. shows the response of frequency deviation comparison for the case study 1. It is clearly understood that the system response with k_p and k_i values obtained by the proposed strategy is showing better results when compared to other algorithms. The simulation is carried out with other prominent algorithms such PSO, Firefly, Harmony Search algorithms and Spider Monkey Algorithms and the results validated the superiority of the proposed algorithm.

Fig.4. shows the comparison of the convergence plot obtained by proposed algorithm with other algorithms. The ITSE value obtained by the proposed algorithm is small and shows better convergence with less number of iterations where as other algorithms exhibits premature convergence.

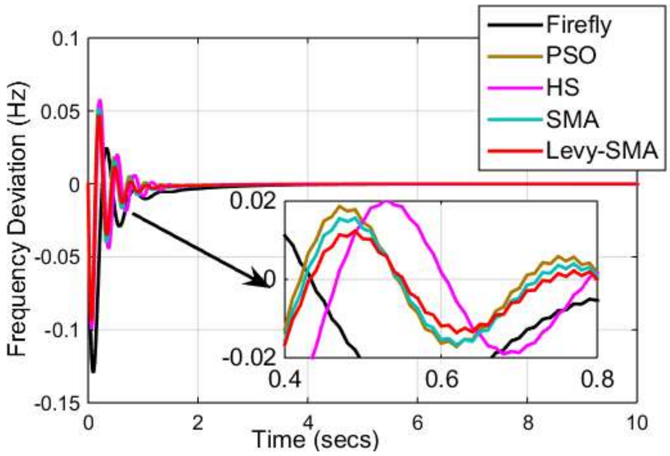

Fig.3. Case study 1: Frequency deviation response with all micro sources

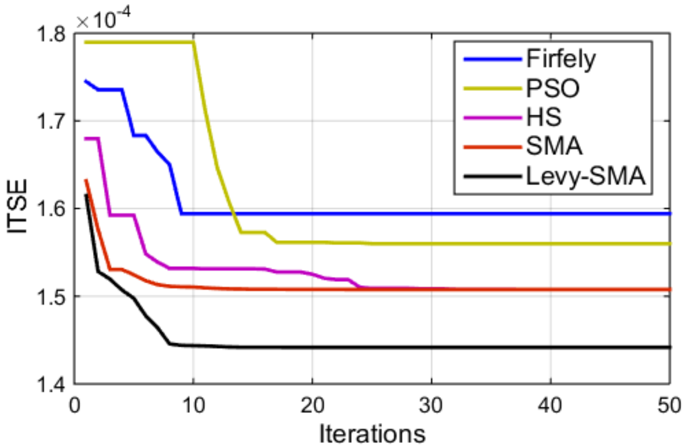

Fig.4. Case study 1: Comparison of convergence plot

Table 2 provides the consolidated optimized values of K_p and K_i values of PI controllers obtained by each individual algorithm. ISE and ITSE values obtained by the proposed algorithm found to be better when compared to other algorithms.

Table 2

Case study 1: Comparison of PI gains and performance metrics values with all sources

Algorithms	PI gains				Performance metrics	
	K_{p1}	K_{p2}	K_{i1}	K_{i2}	ISE	ITSE
Proposed Levy-SMA	4.0746	4.9998	2.079	5	0.0009015	0.0001442
SMA	4.0840	5	1.5720	5	0.0009261	0.0001511
PSO	2.8134	5	5	5	0.0009388	0.0001584
HS	4.0842	5	1.6621	5	0.001205	0.0002158
Firefly	4.1333	5	4.4339	3.3150	0.002268	0.0003839
PSO-fuzzy PI [6]	-	-	-	-	0.00110	-

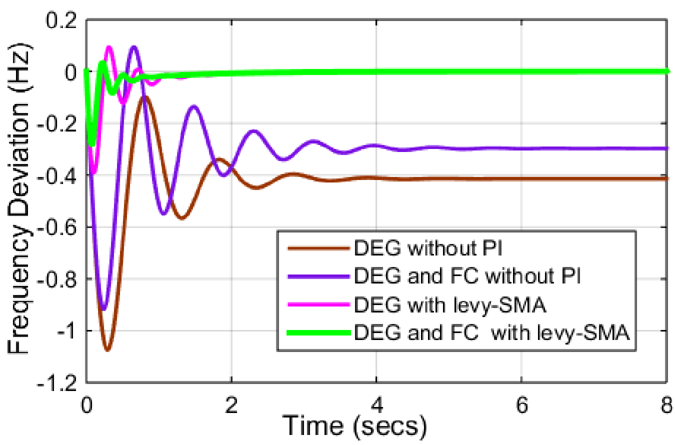

Fig.5. Case study 1: Frequency deviation response with dispatchable sources

Fig.5. shows the response of frequency deviation of the model with the presence of dispatchable sources such as diesel and fuel cells. Here two cases have been examined for frequency control, one with Diesel Engine Generator (DEG) alone and other case including fuel cell contribution in the frequency control. It can be understood that the frequency deviation is considerably improved with fuel cell participation in the frequency control loop. The ISE and ITSE values are 1.074 and 4.4934 respectively with both the dispatchable sources where as with DEG alone, the ISE and ITSE values are 1.966 and 8.636 respectively. Moreover with PI controller action being shared with these dispatchable units have resulted into appreciable amount of improvement in the frequency deviation. Here the ISE and ITSE values are (0.00894 & 0.00134) and (0.0211 &0.00399) respectively for the two cases.

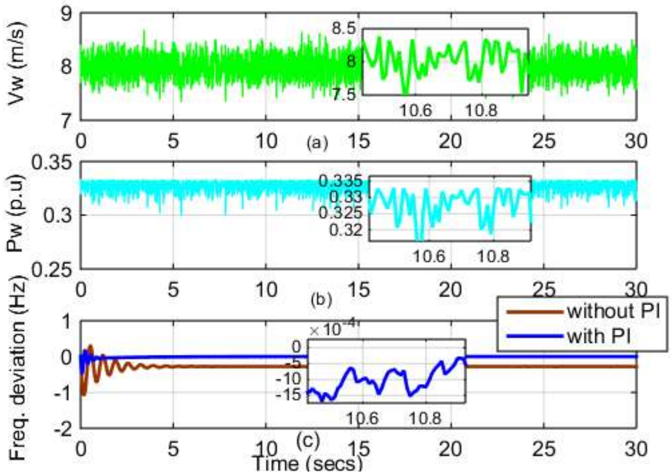

Fig.6. Case study 1: a) Wind velocity b) Generated wind power c) Frequency deviation response with stochastic wind components

Fig.6. shows the simulation results of the model with stochastic wind components. In the previous cases, wind power model is assumed to provide constant power of 1 p.u and the frequency deviation response is obtained without any wind perturbations. To study the system performance and tuned PI controllers capability under wind variations, stochastic wind model is considered. The four wind components in the wind speed model are base wind velocity, gust component, ramp component and noise component. The detailed modelling can be referred from [9].

Fig.6. (a), (b) and (c) shows the wind velocity, generated wind power and the comparison of frequency deviation response of model with and without PI controller action respectively. The base wind velocity is considered as 8 m/sec and there is no gust or ramp components considered in wind speed for this case. The ISE and ITSE values are found to be 0.01067 and 0.02861 respectively.

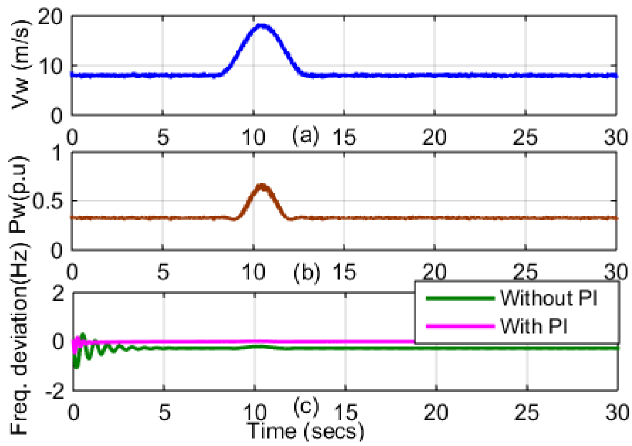

Fig.7. Case study 1: a) wind velocity b) Wind power c)Frequency deviation response with wind gust component

Fig.7. (a), (b) and (c) shows the wind velocity, generated wind power and the corresponding frequency deviation response comparison with and without PI controller action respectively for the case of wind speed with gust of

magnitude of 5 m/secs from 8 to 13 secs. The ISE and ITSE values are found to be 0.02889 and 0.01371 respectively.

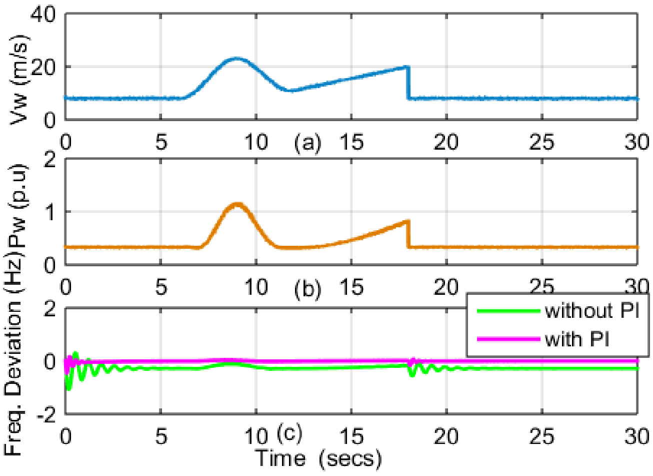

Fig.8. Case study 1: a) Wind velocity b) Wind power c) Frequency deviation response with wind gust and ramp components

Fig.8. (a), (b) and (c) shows the wind velocity, generated wind power and the corresponding frequency deviation response comparison with and without PI controller action respectively for the case of wind speed with sudden gust component for 6 secs with wind velocity of 15 m/sec and ramp components of magnitude of 12 m/secs 8 secs. And Fig.9. shows the response of the other sources such as fuel cell, diesel units and battery to the variations in the wind power. İt is clearly depicted that when there is increased wind power the fuel cell and diesel units reduce their power and the battery is getting charged which is shown as increased battery power. The ISE and ITSE is found to be 0.03317 and 0.07686 respectively with kp and ki values of 2.7009 and 3.9179 for fuel cell and 4.6767 and 0.7365 for diesel unit.

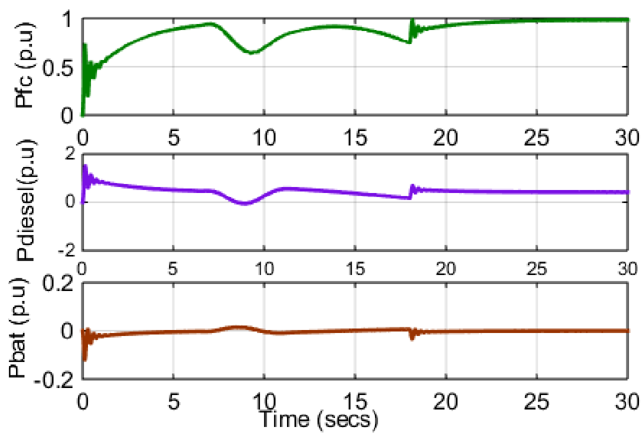

Fig.9. Case study 1: Response of other sources to gust and ramp wind components

4.2. Case study 2

This is the real world micro grid example which is in operation at Bella Coola in North of British Columbia, Canada. This system details and frequency control model are already explained in section 3.2. Two scenarios have been considered for simulation based on the seasonal load variation in the system. The frequency deviation response is obtained for both scenarios i.e., typical winter and summer load conditions.

4.2.1. Scenario 1: Summer load and generation units

The maximum demand of the Bella Coola micro grid is typically around 2.3 MW in summer and is fairly maintained stable throughout the summer. When compared to winter, adequate water level and relatively lower demand during summer leads to maximum share or renewable source in covering the demand. The scenario-1 shows the simulations corresponding to summer load of 2.3 MW which is supplied by two hydro units, fuel cell, aqua electrolyzer and one small diesel unit. Fig.10. shows the frequency deviation response of the scenario-1 without any PI controllers. Fig.11.a. shows the comparison of the frequency deviation response obtained by the proposed algorithm with other algorithms whereas Fig.11.b. shows the comparison response obtained by SMA and Levy SMA algorithm. The response obtained by the proposed algorithm is better in reducing the amplitude of oscillation which results into small ITSE value. The convergence is better in case of proposed algorithm and comparison is shown in Fig.12. Here totally four PI controllers are placed for two hydro units, fuel cell and diesel unit each respectively. Totally eight gain values are optimized.

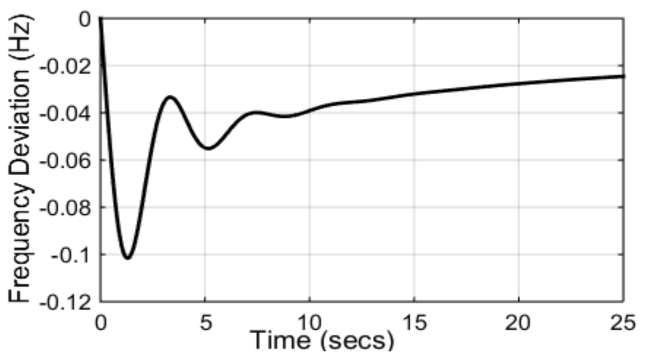

Fig.10. Case study 2: Frequency deviation response without PI controller (Scenario-1)

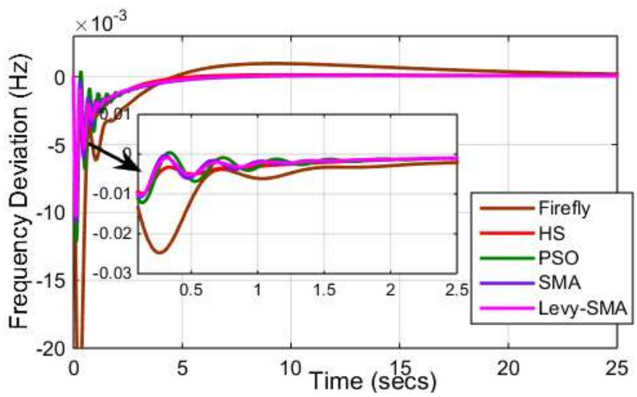

Fig.11.a. Case study 2 - Comparison of frequency deviation response for Scenario-1

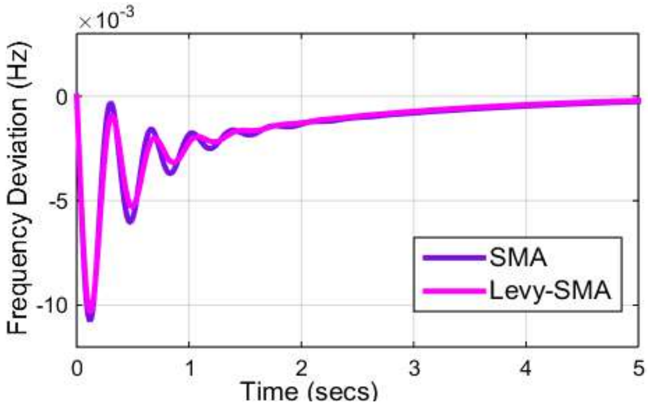

Fig.11.b. Case study 2 - Comparison of frequency deviation response by Levy-SMA and SMA

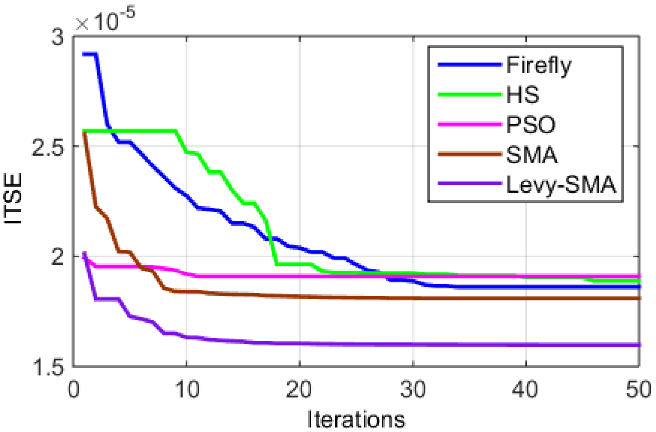

Fig.12. Case study 2 - Comparison of convergence for Scenario-1

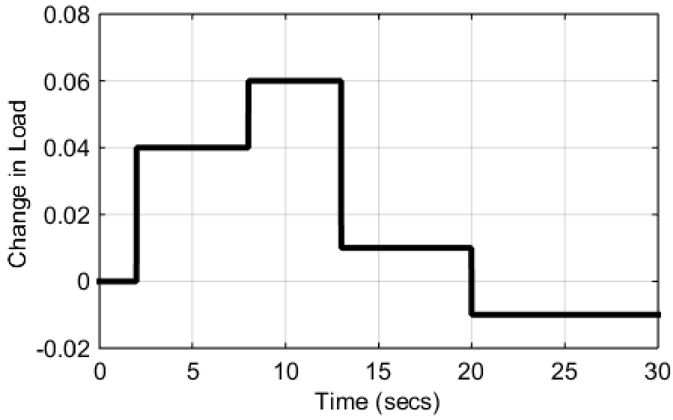

Fig.13. Case study 2 – Variation in load

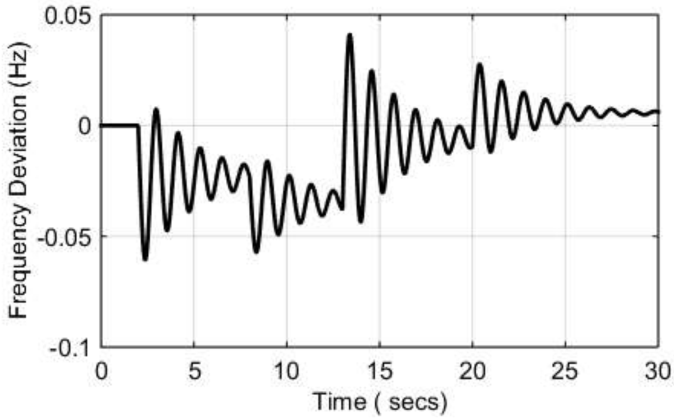

Fig.14. Case study 2 - Frequency deviation response without PI controller (Scenario-2)

Table-3 shows the comparison of optimized K_p and K_i values obtained by the algorithms. The ISE and ITSE values obtained better in case of levy based spider monkey algorithm.

4.2.2. Scenario 2 : Winter load and generation units

This scenario simulates the load frequency control of the Bella Coola micro grid for winter loading condition. Since the winter load demand vary in wide range from 4.3 to 5 MW depending on the winter level, the system response is obtained for continuous load step changes. The step load variations are shown in Fig.13 and the corresponding frequency deviation response without PI controller is shown in Fig.14.

Power generation of the micro sources i.e., Diesel units, fuel cell and aqua electrolyzer for scenario -2 are shown in Fig.15. The increase and decrease in contribution of diesel units during step increase and decrease in the load is respectively shown in Fig.15 and at the mean time there is not much variation in the fuel cell and the aqua electrolyzer due to their limited rating. Since there are no hydro units considered in this scenario-2 due to inadequate water supply during winter, all diesel units are considered. There are 8 PI controllers for all 7 diesel units and one fuel cell and corresponding 16 gains are optimized. The optimized K_p and K_i values and corresponding ISE and ITSE values are tabulated in Table 4.

Table 3
Case study 2 – Comparison of PI gains and performance metrics values for Scenario-1

Algorithms	PI gains								Performance metrics	
	K_{p1}	K_{i1}	K_{p2}	K_{i2}	K_{p3}	K_{i3}	K_{p4}	K_{i4}	ISE	ITSE
Proposed Levy-SMA	6.2713	2.0507	9.9989	2.1401	3.6685	4.9998	10	5	2.59e-5	1.59e-5
SMA	9.9999	2.9001	5.3249	0.5873	10	5	8.9166	5	2.94e-5	1.85e-5
PSO	10	0.1	8.8446	5	0.1	5	10	5	3.47e-5	1.95e-5
HS	0.1302	1.5834	8.3190	4.4350	9.1523	4.8714	9.8728	4.9494	3.22e-5	2.19e-5
Firefly	10	5	10	5	10	5	10	5	0.000222	0.000198

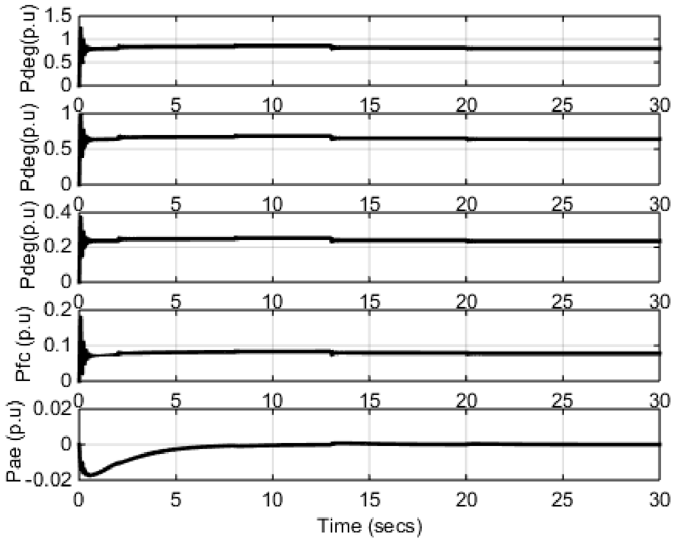

Fig.15. Case study 2 - Power generation by the micro sources

There are 8 PI controllers for all 7 diesel units and one fuel cell and corresponding 16 gains are optimized. The optimized K_p and K_i values and corresponding ISE and ITSE values are tabulated in Table 4. The frequency deviation response for scenario-2 is obtained by the proposed algorithm has been compared with other algorithms which is shown in Fig.16 and the convergence comparison for the same is also shown in Fig.17.

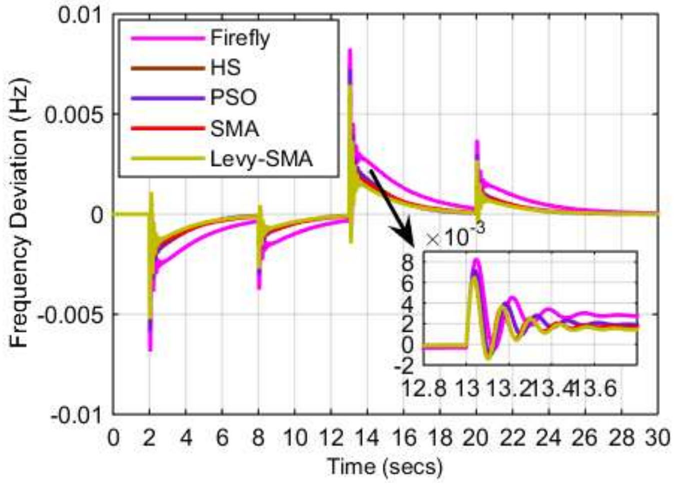

Fig.16. Case study 2 - Comparison of frequency deviation response for scenario-2

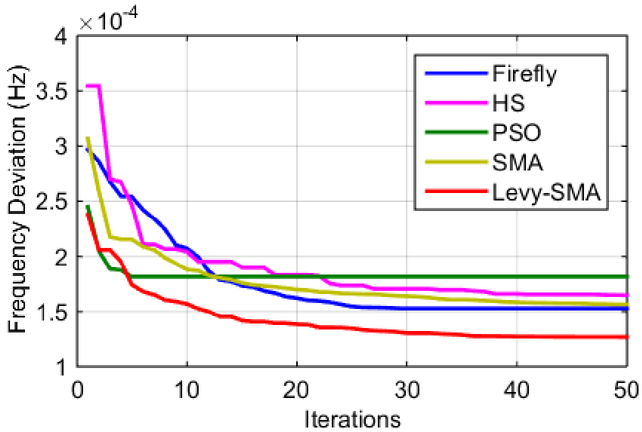

Fig.17. Case study 2 - Comparison of convergence for Scenario-2

Table 4.
Case study 2 - Comparison of PI gains and performance metrics values for Scenario-2

Algorithms	PI gains																Performance metrics	
	K_{p1}	K_{i1}	K_{p2}	K_{i2}	K_{p3}	K_{i3}	K_{p4}	K_{i4}	K_{p5}	K_{i5}	K_{p6}	K_{i6}	K_{p7}	K_{i7}	K_{p8}	K_{i8}	ISE	ITSE
Proposed levy-SMA	9.982	4.997	9.998	5	9.995	4.818	9.996	4.999	9.997	4.994	9.817	4.927	9.984	4.910	3.072	2.208	1.26e-5	0.000131
SMA	10	4.999	9.998	5	9.963	4.721	9.968	4.998	10	4.995	9.987	4.997	7.573	4.978	9.994	2.603	1.50e-5	0.000158
PSO	10	5	0.1	5	10	5	10	5	10	5	10	5	10	5	10	5	1.76e-5	0.000182
HS	8.722	4.798	9.952	4.968	9.177	4.616	9.839	4.734	9.684	4.931	9.151	4.583	9.413	4.971	8.279	4.346	1.69e-5	0.000195
Firefly	10	5	10	5	10	5	10	5	10	5	10	5	10	5	10	5	1.53e-5	0.000501

5. Conclusion

This paper explored a new eagle strategy by combining levy flights and recently budding Spider monkey algorithm. This proposed strategy is utilized for optimizing the gains of PI controllers employed in the frequency regulating circuit of the micro grid. Two case studies have been considered here to implement the frequency control, one of them is a typical micro grid test system and another one is a real time micro grid in operation at British Columbia. Frequency model of both systems were simulated using SIMULINK/MATLAB to analyze its frequency regulation in autonomous mode of operation. The proposed strategy implementation is of two fold search process i.e., coarse search by levy flights and an intensive local search by spider monkey algorithm. Simulation results for various instances confirms that the proposed algorithm performs better than the existing prominent algorithms and proved to be capable enough to tune PI controller gains by tracking perturbation in the system. The performance indices such as ISE and ITSE found by the proposed strategy have been compared with few prominent algorithms for its superiority in finding better gains of PI controllers. Hence, the proposed algorithm can be used for the frequency regulation studies and can be extended frequency regulation within generation scheduling frame.

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